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Visual Acuity vs Letter Contrast Sensitivity in Retinitis Pigmentosa

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This study examined the quantitative relationship between foveal visual acuity and contrast sensitivity for large-letter optotypes in a group of patients with retinitis pigmentosa (RP), in order to assess more completely the extent of foveal vision loss in this group of hereditary retinal dystrophies. High-contrast visual acuity and large-letter contrast sensitivity were measured with a computer-based testing system and with commercially available letter charts (Lighthouse Distance Visual Acuity Test; Pelli–Robson Contrast Sensitivity Chart). Findings from 20 patients with typical RP or Usher syndrome were compared with those from 15 age-similar control subjects with normal vision. On both the computer-based test and the chart tests, the patients with RP showed approximately equal reductions in visual acuity and large-letter contrast sensitivity. However, intersubject variability among the normal controls was greater for contrast sensitivity than for visual acuity on both test protocols. As a result, the patients with RP required a greater reduction in contrast sensitivity than in acuity to exceed the normal range, indicating that visual acuity was the more sensitive index of the loss of foveal visual function.

Retinitis pigmentosa Visual acuity Contrast sensitivity Fovea Vision loss

Retinitis pigmentosa (RP) refers to a group of retinal dystrophies that are typically characterized by night blindness, peripheral visual field restrictions and/or scotomas, abnormalities in the electroretinogram, intraretinal bone spicule-like pigmentation, and narrowing of the retinal vessels (Newsome, 1988). Functional abnormalities of rod and cone systems are typically most apparent in the peripheral visual field, but foveal visual acuity is often reduced as well (Farber, Fishman & Weiss, 1985; Madreperla, Palmer, Massof & Finkelstein, 1990; Alexander, Derlacki, Fishman & Szlyk, 1992b).

While it is apparent that the resolution of fine spatial detail can be compromised in patients with RP, it is uncertain whether their foveal sensitivity to large visual patterns is affected to a similar degree. Some previous studies of foveal contrast sensitivity in RP patients, using grating stimuli, have reported losses of foveal contrast sensitivity primarily at high spatial frequencies (Wolkstein, Atkin & Bodis-Wollner, 1980; Hyvärinen, Rovamo, Laurinen & Peltomaa, 1981). This result suggests that visual acuity would be selectively impaired. Other studies have reported that there are losses of contrast sensitivity at low as well as high spatial frequencies (Lindberg, Fishman, Anderson & Vasquez, 1981; Marmor, 1986; Sucs & Uvijls, 1992), which indicates that the detectability of large stimuli can also be reduced in these patients.

Recently, letter optotypes have been proposed as an alternative to the use of grating stimuli to measure contrast sensitivity (Pelli, Robson & Wilkins, 1988; Regan, 1991). It has been suggested that letters may be more sensitive than grating stimuli to the foveal vision loss of patients with retinal diseases (Herse & Bedell, 1989; Regan, 1991). Therefore it is of interest to compare the loss of contrast sensitivity for large optotypes with the loss of high-contrast visual acuity in patients with RP when letters are used as test targets for both tasks. As discussed by Pelli *et al.* (1988), high-contrast visual acuity and large-letter contrast sensitivity represent defining points on a contrast sensitivity function. Consequently, these measures provide a more complete assessment of the extent of foveal vision loss in RP than is available from visual acuity alone.

In a previous study of contrast sensitivity for letter identification in patients with RP (Alexander, Derlacki & Fishman, 1992a), we determined that contrast sensitivity was reduced for large as well as small letters. However, the quantitative relationship between letter contrast sensitivity and visual acuity *per se* was not addressed. A subsequent study of the effect of target duration on letter identification in patients with RP (Alexander, Derlacki, Fishman & Szlyk, 1992c) suggested that contrast sensitivity for large-letter optotypes might, in fact, be a more sensitive test of foveal dysfunction than the

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measurement of visual acuity. To address this issue more specifically, we assessed the quantitative relationship between visual acuity and contrast sensitivity for large optotypes in patients with RP, using letters as test stimuli for both tasks. We employed two test procedures: (1) commercially available chart tests that utilize letters as optotypes; and (2) a computer-based testing system, similar to that used in our previous study (Alexander *et al.*, 1992c), that allowed a more precise control of various stimulus conditions, such as target duration. We compared the results obtained with the computer-based test protocol to those obtained with the chart tests to determine whether the two types of tests provided comparable measures of foveal vision loss in patients with RP.

METHODS

Subjects

Twenty patients (13 men and 7 women) with typical RP or Usher syndrome [mean ($\pm$SD) age, 38.0 $\pm$ 8.7 yr] participated in the study. On the basis of criteria established previously (Fishman, 1978; Fishman, Kumar, Joseph, Torok & Anderson, 1983), four patients had autosomal dominantly inherited RP [all were type 2 according to the classification schema of Massof and Finkelstein (1981)], one had autosomal recessively inherited RP, 10 had isolated cases of RP (no other family member was known to be affected), two had RP of uncertain genetic type, and three had type 2 Usher syndrome (a recessively inherited variant of RP accompanied by a congenital neurosensory hearing impairment). Patients with RP or Usher syndrome were included in the study if the tested eye had a best corrected pretest Snellen visual acuity that was better than 20/40 [patients with visual acuities worse than this value frequently have posterior subcapsular lens opacities, atrophic-appearing foveal lesions and/or macular cysts (Fishman, Fishman & Maggiano, 1977; Fishman, Anderson & Lourenço, 1985)]. In fact, the patients included in this study had minimal or no lens opacities, no atrophic-appearing foveal lesions, and no macular cysts, although seven eyes had a mild epiretinal macular membrane. The visual field areas of these patients with RP, measured with a II/4e target of a Goldmann perimeter, were all reduced below the lower limit of normal. Consistent with a previous report (Madreperla *et al.*, 1990), the patients with RP showed a statistically significant correlation ($r = -0.65$, $P < 0.01$) between visual field area and visual acuity as measured with a Lighthouse Distance Visual Acuity Test. Findings from the patients with RP were compared with those from 15 (5 men and 10 women) age-similar [mean ($\pm$SD) age, 35.1 $\pm$ 11.7 yr] control subjects with no history of eye disease and a normal ophthalmic examination. Control subjects were unfamiliar with these test procedures, and no acuity criterion was stipulated in their recruitment.

Stimuli

Test stimuli were the set of 10 Sloan letters (NAS-NRC, 1980). The computer-based test procedure has been described previously (Alexander *et al.*, 1992c). In brief, Sloan letters were presented on an Apple high-resolution gray-scale display monitor controlled by a Macintosh II microcomputer. The letters were presented individually in a random order in the center of a background that subtended 1.7 deg horizontally and 1.3 deg vertically. The background was displayed continuously throughout the testing session, and letters were presented as brief luminance decrements in that background. The duration of letter presentation was 0.48 sec, with duration confirmed by a photocell and oscilloscope. The display monitor, which was the only source of illumination in the test area, was placed behind the subjects, with stray light shielded by black cloth, and the letters were viewed monocularly in a front-surface mirror. The background luminance of the screen was 1.9 log cd/m^2 (all luminance calibrations were made with a Spectra Spotmeter). Stimulus luminances were controlled by an ISR Video Attenuator as described by Pelli and Zhang (1991). Linearized color lookup tables that were loaded during the video retrace periods defined the pixel luminances for each video frame. The letters were viewed monocularly through a 2-mm artificial pupil and an appropriate refractive correction in a phorometer at a viewing distance of 7.2 m.

For the chart tests, high-contrast visual acuity was measured with the 2nd edn of the Lighthouse Distance Visual Acuity Test, which was transilluminated by fluorescent lighting such that the background luminance was 2.3 log cd/m^2. The chart was viewed monocularly through a 2-mm artificial pupil and a best correction in a phorometer at a test distance of 4 m. Letter contrast sensitivity was measured with a Pelli–Robson Contrast Sensitivity Chart (Pelli *et al.*, 1988). The chart was illuminated by overhead fluorescent fixtures such that the background luminance was 2.0 log cd/m^2. The chart was viewed monocularly at a distance of 1 m through a best correction placed in a trial frame, with an additional lens to compensate for the test distance. At that viewing distance, each letter subtended approx. 2.7 deg (20/640 Snellen equivalent). Viewing was with the natural pupil, since an artificial pupil restricted the field of view, and it was difficult to accurately place an artificial pupil in the trial frame. For all tests, letter contrast was defined as Weber contrast: $(L_B - L_T)/L_B$, where L_B and L_T are background and letter luminances respectively.

Procedure

Visual acuity was measured first with the Lighthouse chart. Subjects were asked to attempt to read every letter on the chart and to guess if they were uncertain. No time limit was given. Testing was terminated when none of the letters on a line could be identified correctly. The scoring procedure followed the recommendation of Bailey, Bullimore, Raasch and Taylor (1991), in which each letter that was read correctly was assigned a value of 0.02 log MAR, and visual acuity was specified in log MAR units.

Second, measurements of letter contrast sensitivity were made with the Pelli–Robson chart. Subjects were instructed to read each letter on the chart and to guess if they were uncertain. No time limit was given, and, particularly at the lower contrast levels, subjects were encouraged to view the targets for several seconds before responding, as recommended by the testing instructions. Testing was terminated when all letters in a set of three were misread. The scoring procedure followed the recommendation of Elliott, Bullimore and Bailey (1991), in which each letter that was read correctly was assigned a value of 0.05 log unit, and contrast sensitivity was defined as the total score. For both chart tests measurements were made twice, with a different version of the chart used for each of the measurements. The two scores for each test were then averaged.

After measurements were made with the printed test charts, visual acuity and contrast thresholds were measured with the computer-based test. Subjects were first given a brief practice series in which they were required to identify individual Sloan letters presented at a variety of sizes and contrasts. Then, during the actual testing, one of the 10 Sloan letters, chosen randomly by the computer, was presented on each trial at the appropriate size and contrast. A brief warning tone preceded each stimulus presentation. Subjects were instructed to identify verbally which of the letters had been presented, and only responses from the Sloan letter set were accepted. The interstimulus interval was typically 2–3 sec, during which time the subject's response was entered into the computer by the examiner and the next stimulus was generated.

Thresholds for either size or contrast, as appropriate, were measured with a 10-alternative forced-choice staircase procedure. The starting size or contrast was chosen by the experimenter, typically at a presumed suprathreshold level. The initial staircase reversal point was approached by means of a one-down, one-up rule, but subsequent reversals were governed by a two-down, one-up decision rule, which provides an estimate of the 70.7% correct point on a psychometric function, regardless of the number of alternatives (Levitt, 1970). For visual acuity measurements, letters were presented at a fixed contrast of 1.0, and size was altered in 0.1-log MAR steps. For contrast sensitivity measurements, letter size was fixed at 1.0 log MAR (20/200) and contrast was altered in 0.1-log unit steps. Each staircase was run until eight reversals had occurred. Log MAR was measured first, followed by the measurement of contrast sensitivity. After a short rest period, the two tests were then repeated in opposite order, and the final log MAR and log threshold contrast values were defined as the means of the 16 staircase reversals obtained for each test procedure.

RESULTS

Figure 1 presents the log threshold contrast values and the log MAR values of the individual RP patients and control subjects for the computer-based test [Fig. 1(A)] and for the chart tests [Fig. 1(B)] respectively. The pattern of findings was similar for both types of test procedures. For both types of test, the patients with RP showed a statistically significant correlation between log threshold contrast and log MAR ($r = 0.89$, $r = 0.82$, $P < 0.01$, for the computer-based and chart tests respectively). The data points for the patients with RP tended to fall along lines with unit slopes that passed through the mean normal response. Therefore, the patients with RP showed equivalent increases in log MAR and in log threshold contrast for large-letter optotypes.

The normal subjects showed approximately twice the SD for log threshold contrast as for log MAR (0.10 vs 0.05 for the computer-based test; 0.08 vs 0.04 for the chart tests). This is indicated by the fact that the ellipses in Fig. 1, which represent the 95% confidence limits for the normal subjects (i.e. the region within which 95% of the

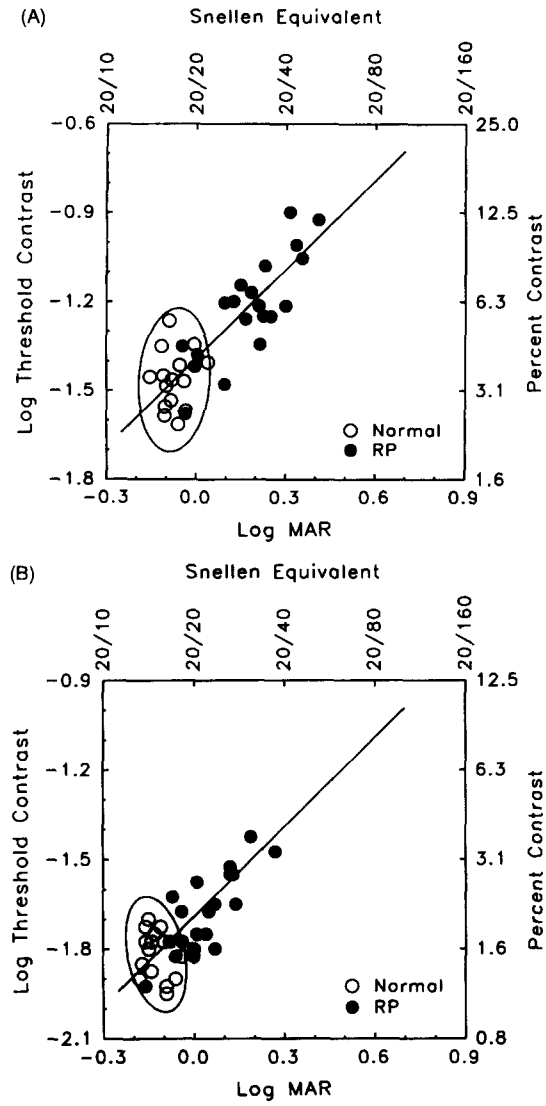

FIGURE 1. Log threshold contrast vs log MAR for individual patients with RP and normal controls. The Snellen equivalents of the log MAR values are indicated at the top; the linear percentage contrasts are indicated on the right. The ellipses represent 95% Gaussian bivariate ellipsoids fit to the normal data. The lines have unit slope and pass through the mean of the normal results. (A) Data obtained with the computer-based test. (B) Data obtained with the Lighthouse and Pelli–Robson charts.

results from the normal subjects are expected to fall), had a longer axis vertically than horizontally. As a result of this asymmetry in variability among the normal subjects, fewer patients with RP had values of log threshold contrast that exceeded the normal limits (i.e. data points above the ellipses) than had log MAR values that were greater than normal (i.e. data points to the right of the ellipses). For example, on the computer-based test, 16 of the 20 RP patients had values of log MAR that were greater than normal, while only nine had values of log threshold contrast that were greater than normal. Therefore, even though the patients with RP showed approximately equal changes in log MAR and in log threshold contrast, log MAR appeared to be the more discriminating measure of foveal dysfunction.

DISCUSSION

The patients with RP in this study showed a significant correlation between their loss of visual acuity and their loss of contrast sensitivity when tested with large-letter optotypes. As is illustrated in Fig. 1, the log MAR values and log threshold contrasts of the RP patients were elevated above normal by an approximately equal amount, whether measurements were made with the computer-based test or with the chart tests. Therefore, not only was fine spatial vision impaired in these patients, but the identifiability of large patterns was reduced as well. This result is consistent with previous reports that grating contrast sensitivity may be reduced at low spatial frequencies in patients with RP (Lindberg *et al.*, 1981; Marmor, 1986; Sucs & Uvijls, 1992) and shows further that, at least for letter identification, the loss of contrast sensitivity for large patterns is directly proportional to the loss of visual acuity.

The log MAR values of the normal subjects as measured with the Lighthouse chart were consistent with previous studies of visual acuity in normal subjects, showing log MAR values better than 0.0 (Snellen equivalent of 20/20) (Pardhan & Elliott, 1991). Consequently, a visual acuity value of 20/20 as measured with a standard clinical chart should not necessarily be interpreted as representing normal visual acuity when testing patients with RP and other visual disorders. The visual acuity values of both the normal subjects and the patients with RP tended to be worse on the computer-based test than on the Lighthouse chart. A likely explanation is the somewhat lower retinal illuminance (by 0.4 log unit) of the computer-based test. On the basis of our previous data (Alexander, Derlacki, Fishman & Peachey, 1991), a reduction in retinal illuminance of this magnitude would be expected to reduce visual acuity to the extent seen here. The stimulus conditions used in the computer-based test provided a greater separation between the normal subjects and the patients with RP than did the chart tests. Therefore, our results provide additional evidence that differences in visual acuity between normal subjects and those with abnormal visual systems are enhanced at luminances that are lower than those used in standard clinical tests of visual acuity (Adams, Wong, Wong & Gould, 1988; Taub & Sturr, 1991).

For the normal subjects, the log threshold contrast values obtained with the Pelli–Robson chart compared favorably with those of previous reports (Pardhan & Elliott, 1991; Elliott & Bullimore, 1993). However, the log threshold contrast values obtained with the computer-based test protocol were approx. 0.3 log unit higher than those obtained with the Pelli–Robson chart. We examined the possibility that the difference in letter sizes used on the two tests was a contributing factor by measuring contrast sensitivity in seven normal subjects using letters presented on the computer screen at a viewing distance of 2.7 m, which provided letters of the same log MAR value as on the Pelli–Robson chart and also increased the angular subtense of the background field. Under these test conditions, the mean value of log threshold contrast was −1.49 (SD 0.18) for the larger letters vs −1.46 (SD 0.12) for letters of 20/200 Snellen equivalent, a difference that is not sufficient to account for the disparity between the results for the Pelli–Robson chart and the computer-based test. Another possible explanation for the difference in log threshold contrast values between the two tests is the slight difference in retinal illuminance levels (0.3 log unit). However, based on our previous results (Alexander *et al.*, 1992a), a difference in retinal illuminance of this magnitude should not result in the difference in log threshold contrast that we observed in the normal subjects on the two tests. A more likely reason for the difference in log threshold contrast is the difference in viewing time used in the two test procedures, since it has been demonstrated that a prolonged viewing time, as was used for the Pelli–Robson chart, can increase the contrast sensitivity score (Elliott & Whitaker, 1992), an effect that is much more pronounced for contrast sensitivity than for visual acuity.

The equivalent increase in the log threshold contrast values and the log MAR values for the RP patients indicates that these patients did not have an overall reduction in letter contrast sensitivity. An overall reduction in contrast sensitivity would produce a greater change in log threshold contrast for large letters than in log MAR, due to the relatively steep slope of the letter contrast sensitivity function at small letter sizes (e.g. Alexander *et al.*, 1992a). Furthermore, the linear relationship between log threshold contrast and log MAR argues against a selective loss of contrast sensitivity for high spatial frequencies in these RP patients. Such a selective contrast sensitivity loss would have produced a greater change in log MAR than in log threshold contrast for large letters. However, the exact explanation for the linear relationship between log threshold contrast and log MAR in these patients with RP remains to be determined.

The normal subjects in our study showed approximately twice the SD for log threshold contrast as for log MAR. A similar difference in variability among normal subjects can be seen in the data of Pardhan and Elliott (1991), who compared Pelli–Robson contrast sensitivity with log MAR values obtained with a

Ferris–Bailey chart. This asymmetry in variability among the normal subjects could be explained if the major source of intersubject variability among the normal subjects were an overall change in letter contrast sensitivity. As noted above, an overall change in contrast sensitivity would produce a greater change in large-letter contrast sensitivity than in visual acuity, which would result in a greater variability in letter contrast sensitivity values.

In conclusion, this group of 20 patients with RP or Usher syndrome showed reductions in contrast sensitivity for large letters that were approximately equal to their reductions in visual acuity. A similar pattern of results was obtained with a computer-based test procedure and with commercially available chart tests, although deficits were greater overall on the computer-based test. Therefore, the decrease in foveal visual function in these patients was not limited to the loss of fine pattern vision but extended to large optotypes as well. The degree of intersubject variability among the normal subjects was twice as great for letter contrast sensitivity as for visual acuity. As a consequence, the measurement of contrast sensitivity was not as sensitive to the loss of foveal visual function in these patients with RP as was the evaluation of visual acuity. A similar consideration would apply to the measurement of visual acuity and contrast sensitivity in other visual disorders as well.

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